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On the rotifer fauna of Bermuda, including notes on the associated meiofauna and the description of a new species of *Encentrum* (Rotifera: Ploima: Dicranophoridae)

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Abstract.—The rotifer fauna of Bermuda was investigated by examining samples from 12 localities, including marine, brackish, and freshwater localities. The majority of the 14 species that were identified are common cosmopolites, but some also have a more limited distribution. No endemics were recorded. The dominant genus present in the samples, *Lecane,* was represented by 5 species. The relatively small total number of species is probably due to one or both of two factors: the lack of stable freshwater bodies, and Bermuda's isolated geographic position. All but one of the recorded species are new to Bermuda. One species, *Encentrum astridae,* is new to science. The species has previously been found in Danish waters. Finding the new species in both Danish and Bermudan waters suggests that it is distributed in at least the boreal and tropical West Atlantic regions.

Few studies concerning rotifers from isolated oceanic islands have been accomplished. However, to understand the zoogeographic dynamics and dispersal potential of rotifers it is important to know the distribution of these island-dwelling species. These include Galapagos (De Smet 1989a, 1989b; Segers & Dumont 1993a), the Easter Island (Segers & Dumont 1993a), the South Pacific islands (Russell 1957), and the Azores (Green 1992). This study presents the first faunistic study on the rotifer fauna of the Bermuda archipelago. The localities studied include marine, brackish, and freshwater bodies.

Bermuda is located in the Atlantic Ocean at about 32°N, 64°W, almost 1000 km SE of North Carolina, USA, which represents the nearest continental coast. The Bermuda seamount was first formed by volcanic eruptions about 100 mya, and re-erupted 35 mya, covering an area much larger than the present area of Bermuda. Subsequent erosion, formation of coral reefs, a covering of limestone accreted by the wind-blown skeletons of reef organisms, and the postglacial rise of the sea level formed the islands' present appearance (Watson et al. 1965).

On land, dune hills and limestone dominate Bermuda. There are no streams or rivers and only a few canals. A few lakes and ponds are present, but all are to some extent connected with the sea and therefore permanently or temporarily brackish.

Bermuda's location in the Gulf Stream provides the islands a climate with hot summers and mild winters. This enables the corals to form large reefs, and provide the calcareous coral sand that dominates the sea floor around Bermuda. This coral sand has proved to host a rich marine interstitial fauna (Higgins 1982; Eibye-Jacobsen & Kristensen 1994; Sterrer 1998a, 1998b). For a more comprehensive review of the Bermudan fauna see Sterrer (1986).

Materials and methods

During a three-weeks stay at the Bermuda Aquarium Museum and Zoo (BAMZ), six-

teen localities were sampled for the purpose of collecting rotifers and gnathostomulids (Fig. 1). Seven marine, four brackish, and one freshwater station yielded rotifers (Tables 1, 2).

Intertidal samples were dug up with a shovel, while subtidal samples were taken by snorkeling. In both cases the upper 10 cm of the sediment was collected, placed in buckets, and returned to the laboratory for processing. Meiofaunal organisms were extracted from the sediment by using an isotonic solution of magnesium sulfate to anaesthetize the animals. Approximately 1 liter sediment was transferred to a conical plastic bottle and a corresponding amount of magnesium sulfate solution was added. After a ten minutes incubation period the containers were agitated vigorously, and after a brief period settling the supernatant was decanted through a 30 μm mesh sieve. This procedure was repeated once. Samples taken from detritus, algae and plants were squeezed and concentrated in a 30 μm mesh sieve.

All samples were sorted using a Wild M420 dissection microscope and a Wild M20 microscope. Rotifers were identified and drawn using a Wild M20 compound microscope with camera lucida. Trophi were isolated by dissolving the animals using dilute sodium hypochlorite and then prepared for SEM and light microscopy (De Smet 1998). Trophi for light microscopy were mounted in a modified Faure's solution. Trophi for SEM were examined and photographed with a JEOL JSM-840 microscope. All material is deposited in the Zoological Museum, University of Copenhagen (ZMUC).

Results

Sixteen localities investigated yielded a total of 14 identified rotifer species, two forms of the same species, a number of unidentified bdelloid species from the genera *Philodina* and *Rotaria,* and one dead specimen of *Monommata* which could not be identified. All recorded species are listed in Table 3.

Five species, of the genera *Colurella, Encentrum,* and *Proales,* were recorded from the marine localities. One of these, *Encentrum astridae* new species, is new to science. The brackish water localities yielded eight species, distributed among six genera. Furthermore, some unidentified *Rotaria* were recorded. Two species, *Colurella uncinata uncinata* and *Proales similis,* occurred both at marine and brackish localities. The single freshwater locality produced three identified species, one unidentified *Monommata* and some *Philodina* spp. *Colurella uncinata* was recorded from the freshwater locality as well as from a brackish and a marine locality. In the freshwater locality the species was represented by the form *C. uncinata bicuspitata.*

The remaining interstitial fauna at the marine localities was only investigated superficially. However, it was noted that the samples contained a rich meiofauna. Most samples contained several species of macrodasyid gastrotrichs, including the easily recognized genus *Urodasys.* Nematodes were numerous, including different desmoscolecids. Also several interstitial polychaetes, including the families Dorvilleidae and Syllidae were represented. Five species of Gnathostomulida, *Haplognathia rosea* (Sterrer, 1969), *Tenuignathia rikerae* Sterrer, 1976, *Problognathia minima* Sterrer & Farris, 1975, *Gnathostomula peregrina* Kirsteuer, 1964, and *Austrognathia christianae* Farris, 1977, were recorded. *Gnathostomula peregrina* was the most abundant and was present at stations 3–7. Two species of Kinorhyncha, *Antygomonas* cf. *oreas* Bauer-Nebelsick, 1996 and *Echinoderes bermudensis* Higgins, 1982, were recorded from station 7 and 4, respectively. Except for the arrangement of the lateral spines on segment 11 the *Antygomonas* species fits perfectly the description given by Bauer-Nebelsick (1996). In the specimens described by Bauer-Nebelsick (1996) the cuspidate spines are located laterally to the acicular

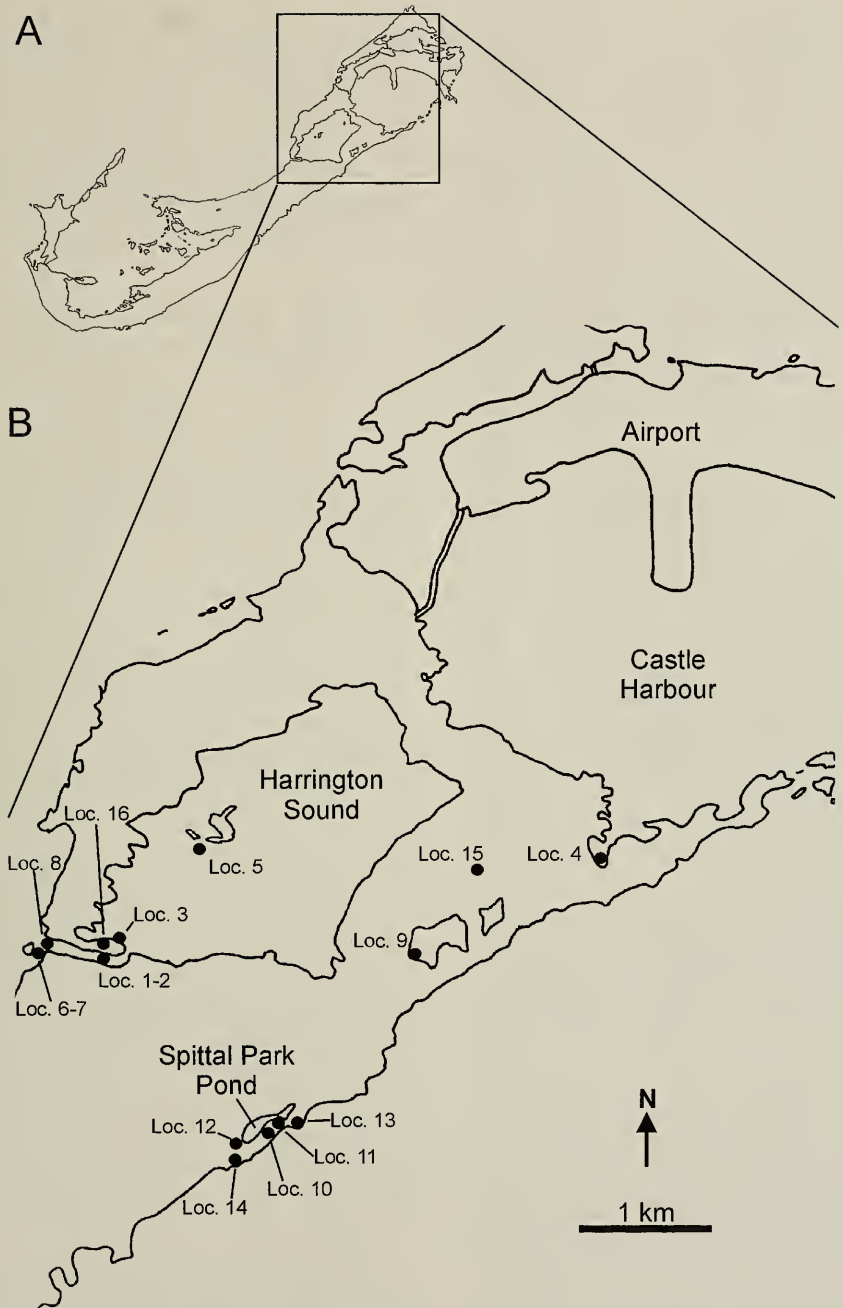

Fig. 1. Map showing location of sampling sites on Bermuda. Localities 2, 13, 14, and 15 yielded no rolifers and are omitted in the following tables, thus Loc. 1 = st. 1, Loc. 2 = st. 2, Loc. 4 = st. 3, Loc. 5 = st. 4, etc., and Loc. 16 = st. 12.

Table 1.—Data on marine localities. Salinity on all stations ca. 33‰.

St. No.	1	2	3	4	5	6	7
Name	Flatts Inlet	BAMZ docks	Tuckers Town Cove	At Trunk Island	Gibbon Bay	Gibbon Bay	Mouth of Flatts Inlet
Position	32°19′19″N 64°44′17″W	32°19′21″N 64°44′10″W	32°19′49″N 64°41′30″W	32°19′51″N 64°43′39″W	32°19′16″N 64°44′31″W	32°19′16″N 64°44′31″W	32°19′18″N 64°43′32″W
Coll. Date	6 Sep 2000	6 Sep 2000	7 Sep 2000	7 Sep 2000	15 Sep 2000	17 Sep 2000	15 Sep 2000
Depth	1 m	2 m	—	3 m	0.5 m	—	3 m
Temp.	28.4°C	28°C	28.3°C	27°C	28.2°C	29.2°C	28.2°C
Remarks	Subtidal, from fire sponges, *Tedania ignis*	Subtidal, from red algae on reef and docks	Intertidal, from medium coral sand w. detritus	Subtidal, from medium coral sand w. detritus	Subtidal, from fine coral sand w. detritus	Intertidal from fine, clean coral sand	Subtidal, from medium, clean coral sand

spines, while the position of these have shifted in the Bermuda specimen, so the acicular spines on segment 11 are most lateral. *Antygomonas oreas* was described from coral sand at relatively deep water (500–600 m) in the Pacific Ocean (Bauer-Nebelsick, 1996). This is the first reported record of the species since then.

Family Dicranophoridae Harring, 1913
Genus *Encentrum* Ehrenberg, 1838
Encentrum astridae, new species
Figs. 2–3

Type material.—All type material was obtained from samples taken on 15 September 2000 at station 5, Gibbon Bay close to Flatts Inlet, Bermuda (Table 1). Position: 32°19′16″N, 064°44′31″N. Holotype: Adult female, mounted in glycerol (ZMUC ROT-223). Paratypes: 9 adult females, mounted in glycerol (ZMUC ROT-224 to ROT-232); 2 isolated trophi mounted for LM (ZMUC ROT-233 and ROT-234); 3 isolated trophi from adults mounted for SEM (ZMUC ROT-235 to ROT-237); 1 isolated trophus from a juvenile mounted for SEM (ZMUC ROT-238). All types are stored at ZMUC.

Other material.—Further material was obtained 7 July 1999, at Præstebugten, Hirsholmene, Denmark, a small group of islands in the northern Kattegat off Frederikshavn, Denmark. Samples were taken in the tidal zone from well-sorted medium sized quartz sand covered with sulfur bacteria. Position: 57°29′17″N, 010°37;′29″E. 2 isolated trophi mounted for SEM (ZMUC ROT-244 and ROT-245) and stored at ZMUC.

Diagnosis.—Large animals (ca. 350 μm long), trunk with longitudinal folds (Fig. 2A–B). Foot ventrally displaced (Fig. 2B). Posterior part of stomach covered by yellowish to brownish glandular syncytium with brown nuclei (Fig. 2A–B). Trophi large, forcipate. Rami large with sharp apical rami teeth, and a pair of smaller, hook-shaped preuncinal teeth. Unci very long, almost as long as rami length, with sharp in-

Table 2.—Data on brackish and fresh water localities. All samples taken just below the water surface.

St. No.	8	9	10	11	12
Name	Mangrove Lake	Bird Sanctuary Pond	Spittal Pond, east	Spittal Pond, west	Pond in Zoo, BAMZ
Position	32°19′26″N 64°42′38″W	32°18′34″N 64°43′33″W	32°18′39″N 64°43′29″W	32°18′32″N 64°43′39″W	32°19′20″N 64°44′18″W
Coll. Date	7 Sep 2000	12 Sep 2000	12 Sep 2000	14 Sep 2000	15 Sep 2000
Salinity	10–15‰	3–8‰	12–18‰	7–12‰	0‰
Temp.	27°C	26.4°C	25.6°C	29.6°C	25.1°C
Remarks	From algae on mangrove roots	From red bacteria mats and degraded plants	From detritus and degraded plants	From detritus and degraded plants	From plankton, algae and plants

ward-curved teeth. Supramanubria with long curved extensions, meeting each other in center of trophi (Figs. 2C, 3).

Description.—Body elongate, fusiform. Head medium size; rostrum short; corona slightly oblique, ventrally. Brain large, saccate, extending into neck; subcerebral glands elongate; no light-refracting elements; retrocerebral sac absent; eyespots absent (Fig. 2A–B). Neck short. Trunk with three distinct tranverse folds; posterior pseudosegment with broad tail. Dorsal and lateral sides of trunk with irregularly distributed longitudinal folds. Mastax large, with pair of salivary glands. Proventriculus present. Stomach surrounded by yellowish to brownish glandular syncytium with brown nuclei; number of nuclei ranging between 12 and 19 (Fig. 2A–B). Gastric glands elongate, close to stomach. Vitellarium large, elongate. Foot long, conical, retractable, ventrally displaced (Fig. 2A–B). Toes close-set, almost parallel sided, tapering distally to tips. Pedal glands elongate, narrow (Fig. 2A–B).

Trophi forcipate, large, elongate, slender (Figs. 2C, 3). Rami expanded ¼ from proximal ends; outer margins slightly concave medially, slightly diverging distally (Figs. 2C, 3A–C). Median opening wedge-shaped. Each ramus tip terminating dorsally in a sharp, slightly curved, inwardly projecting apical ramus tooth (Figs. 2C, 3A, C); ventrally, at bases of apical rami teeth, a small, stout, slightly hook-shaped, inwardly projecting preuncinal tooth (Figs. 2C, 3B, D). Scapus long, narrow, extending into anterior part of ramus (Fig. 2C); fenestra of scapus small, opening basally on dorsal side of each ramus (Fig. 3C). Bulla small, almost rectangular (Fig. 2C); fenestra of bulla small, opening caudally on ramus (Fig. 3D, F). Fulcrum rod-shaped in dorsal view (Figs. 2C, 3A–C), gradually tapering towards truncate tip in lateral view (Fig. 3D). Unci very long, almost 9/10 of rami length; shaft long, rod-shaped; teeth long, sharp, inwardly curved, with small dorsal apophysis at bases (Figs. 2C, 3). Manubria gradually

Table 3.—Occurrence of rotifer species at stations 1 to 12.

Stations	1	2	3	4	5	6	7	8	9	10	11	12
Brachionus urceolaris (Müller, 1773)									X			
Cephalodella forficata (Ehrenberg, 1832)											X	
Colurella colurus (Ehrenberg, 1830)	X			X	X		X					
C. obtusa (Gosse, 1886)												X
C. uncinata uncinata (Müller, 1773)		X						X				
C. uncinata bicuspitata (Ehrenberg, 1832)												X
Encentrum astridae new species		X	X	X	X	X	X					
Encentrum tectipes Remane, 1949		X		X	X	X	X					
Rotaria spp.										X		
Lecane bulla (Gosse, 1851)								X				
L. closterocerca (Schmarda, 1859)												X
L. grandis (Murray, 1913)										X		
L. hastata (Murray, 1913)										X		
L. punctata (Murray, 1913)										X		
Monommata sp. indet.												X
Philodina spp.												X
Proales similis De Beauchamp, 1907							X			X	X	

curved inwardly towards distal ends (Figs. 2C, 3); proximal ends with anterior and median chamber retained. Anterior chamber present in dorsally pointed extension; median chamber with small fenestra ventroapically on manubrium. Intramallei small, triangular, attached to ventral side of supramanubria (Figs. 2C, 3B). Supramanubria very large, with stout bases tapering into long extensions with curved terminals; terminals meet each other in center of trophi (Figs. 2C, 3A–C).

Juveniles about 2/3 of adult size; very hyaline, no coloration of any organs yet; trophi as in adults (Fig. 3B). No males were found.

Measurements of adult females: Body length 308–388 μm; toes 26–31 μm; trophi 38 μm; rami 22 μm; fulcrum 10 μm; unci 19 μm; manubria 24–26 μm; intramallei 3 μm; supramanubria 10 μm.

Etymology.—The species is named after my daughter Astrid.

Remarks.—The presence of relatively simple forcipate trophi with intramallei and supramanubria, and a long fulcrum, combined with the absence of teeth on inner margins of rami and single-toothed unci clearly place *Encentrum astridae* new species in the genus *Encentrum* (see De Smet 1997). The presence of elongate rami with very long scapus, dorsal incurved apical ramus teeth and ventral preuncinal teeth set at right angles to rami place the species in subgenus *Encentrum* s. str. Ehrenberg, 1838 (see De Smet 1997).

The species can hardly be confused with other known species due to the presence of large trophi with very long unci with inwardly pointed teeth, and long supramanubrial extensions reaching each other (Figs. 2C, 3A–C).

The species was found at five of the investigated marine localities (see Table 3), and is probably common in the psammon around Bermuda. It was found in intertidal as well as subtidal psammon, but was most abundant in the subtidal. It occurred on depths ranging from 0 to 3 meter. In June

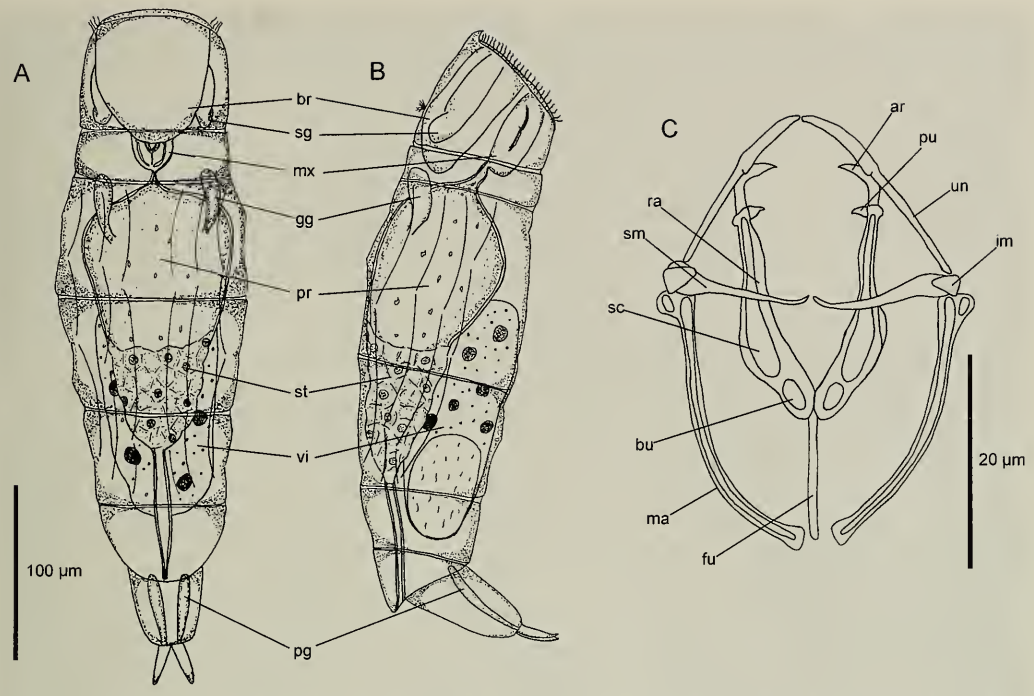

Fig. 2. *Encentrum astridae* new species. A. Female habitus, dorsal view. B. Female habitus, lateral view. C. Trophi, ventral view. Abbreviations: ar, apical ramus tooth; br, brain; bu, bulla; fu, fulcrum; ga, gastric glands; gl, glandular syncytium; im, intramalleus; ma, manubrium; mx, mastax; pg, pedal glanda; pr, proventriculus; pu, preuncinal tooth; ra, ramus; sc, scapus; sg, subcerebral glands; sm, supramanubrium; st, stomach; un, uncus; vi, vitellarium.

1999 it was found in psammon samples from Danish waters. The species was found during meiofauna collections on Hirsholmene, a small group of islands in the northern part of Kattegat, off Frederikshavn, Denmark, but was not described then due to insufficient material. This distribution suggests that the species may be found in well-sorted sandy sediments at shallow waters in most of the Northern Atlantic.

Discussion

No systematic study has been made of the Bermudan rotifer fauna before. Only four species were previously recorded, and none of these were identified to more than genus level (von Bodungen et al. 1982; Sterrer 1986, 1998a). von Bodungen et al. (1982) recorded *Trichocerca* sp. from Hamilton Harbour and Sterrer (1986) reports *Encentrum* sp., *Lindia* sp., and *Synchaeta* sp. from different localities, and illustrates the recorded species (Sterrer 1986: plate 69). *Encentrum* sp. is probably identical to *Encentrum tectipes* (Fig. 4A–B). *Lindia* sp. is identical to *L. tecusa* Harring & Myers, 1922, due its presence in sublittoral psammon. This identity was confirmed during my stay at BAMZ, where I had the opportunity to investigate unpublished LM pictures of the species. The species was not recorded during this study, and Sterrer (1986) refers to it as "rare". Neither *Synchaeta* sp. nor *Trichocerca* sp. were recorded in this study. Both species were found in planktonic samples (von Bodungen et al. 1982; Sterrer 1986), and since the marine samples in this study only were taken from psammon or phyton, it explains why these were not recorded. Based solely on the illustrations, the *Synchaeta* species reported by Sterrer (1986) cannot be identified. von

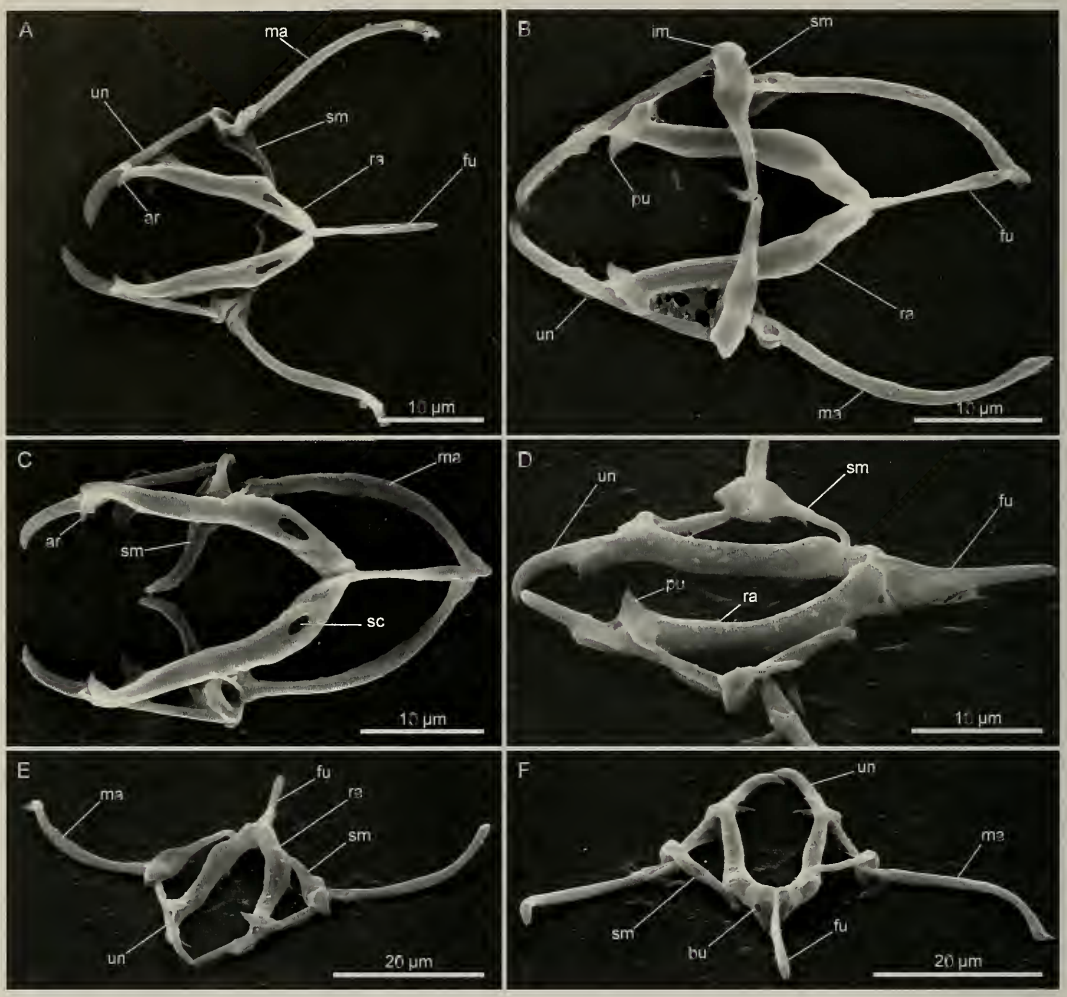

Fig. 3. *Encentrum astridae* new species. SEM photos of trophi. A is a Danish specimen, B–F is Bermudan specimens. A. Dorsal view. B. Ventral view, from juvenile specimen. C. Dorsal view, rami opened. D. Lateral view. E. Frontal view. F. Caudal view. Abbreviations: ar, apical ramus tooth; bu, bulla; fu, fulcrum; im, intramalleus; ma, manubrium; pu, preuncinal tooth; ra, ramus; sc, scapus; sm, supramanubrium; un, uncus.

Bodungen et al. (1982) do not illustrate the recorded *Trichocerca* sp, but it might be identical to *T. marina* (Daday, 1890), which is the only known marine planktonic *Trichocerca.*

Lecane was the dominating species and accounted for 31% of the total amount of identified species. Though the material in this study is rather small, it confirms the pattern that *Lecane* displays high species diversity in tropical and subtropical regions (see Harring 1914; De Smet 1988; Segers & Dumont 1993a, 1993b, 1995; Segers & De Meester 1994; Segers & Sanoamuang 1994; Janetzky et al. 1995; Sanoamuang 1998; Samraoui et al. 1998).

A few specimens of *Cephalodella forficata* (Fig. 4E–F) were recorded from one of the brackish water localities (Table 3). All specimens were juveniles, and the gastric glands were only light red. The species is considered cosmopolitan, but is mainly found in freshwater (Koste 1978; Nogrady & Pourriot 1995).

Proales similis (Fig. 4C–D) was found at brackish as well as marine localities (Table

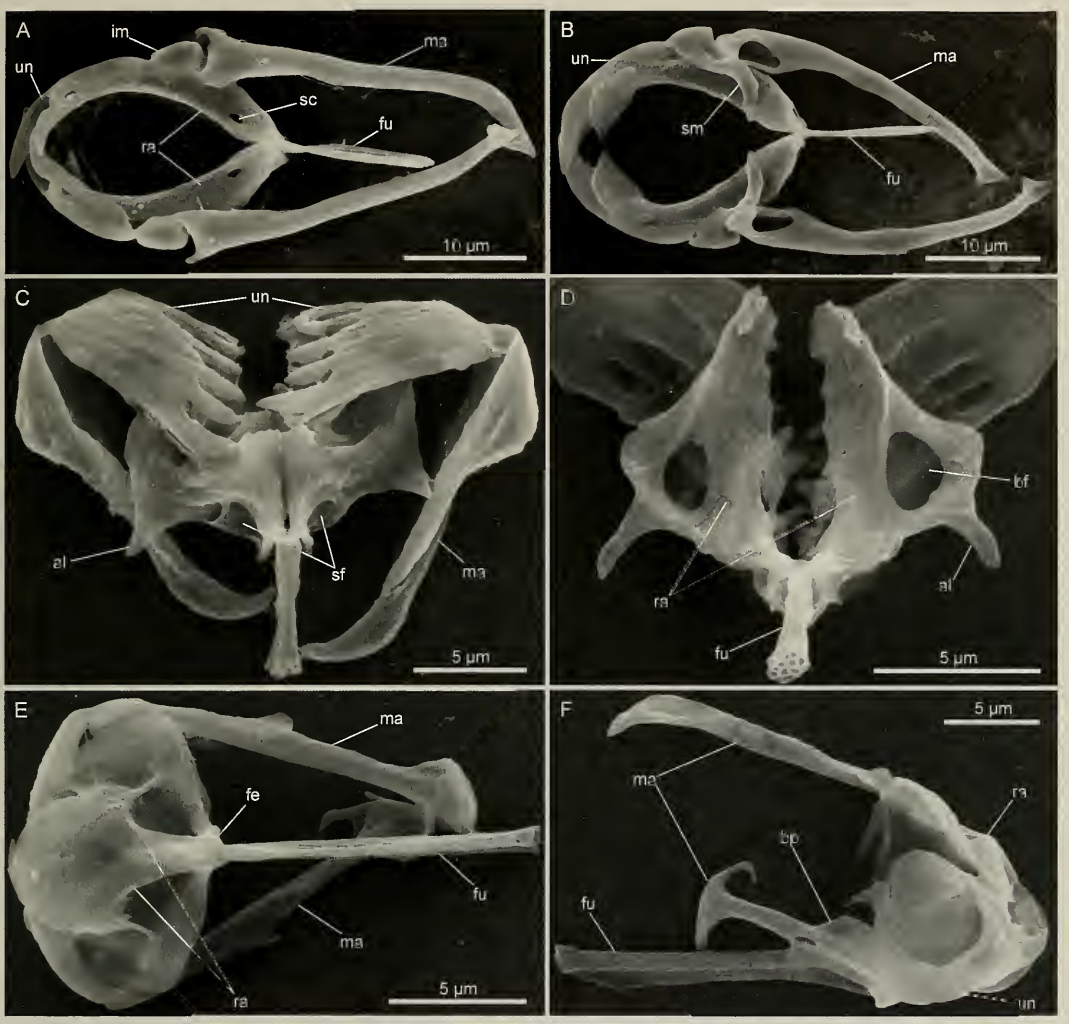

Fig. 4. SEM photos of trophi. A. *Encentrum tectipes,* dorsal view. B. *E. tectipes,* ventral view. C. *Proales similis,* ventral view. D. *P. similis,* rami, dorsal view. E. *Cephalodella forficata,* ventral view. F. *C. forficata,* lateral view. Abbreviations: al, alula; bf, basifenestra; bl, basal lamella; fe, fulcral extension; fu, fulcrum; im, intramalleus; ma, manubrium; ra, ramus; sc, scapus; sf, subbasifenestra; sm, supramanubrium; un, uncus.

3). The species is recognized by its fusiform trunk and offset foot with one pseudosegment and distinct wrinkles. The apical rami tips were rather short (Fig. 4D) in the recorded specimens, and not extended as in the specimens pictured by De Smet (1996). The species has been recorded from most parts of the world and is found in marine waters as well as inland saline or brackish ponds (De Smet 1996).

Beside *Encentrum astridae* new species, another dicranophorid, *E. tectipes,* was recorded from the marine localities. The species is easily recognized by its robust and compact trophi (Fig. 4A–B), and the presence of yellowish glandular tissue around the posterior part of the stomach, also described by Remane (1949). Like many other marine, interstitial dicranophorids, the species has formerly only been recorded from the northwestern Europe (De Smet 1997), but finding the species on Bermuda suggests that it is much more widely distributed. As a matter of fact, the known distri-

butional patterns of many marine, interstitial rotifers with an apparently limited distribution are probably mostly a reflection of our insufficient knowledge of species from such habitats, rather than a picture of their actual distribution. Recently, *E. tenuidigitatum* De Smet, 2000, described from tidal psammon in Belgium, was recorded from Greenland (Funch & Sørensen 2001), and *E. porsildi* Sørensen, 1998 described from Disko Island, Greenland, was recorded from Denmark (Sørensen, in press). I find it very likely that the interstitial habitat in clean, well-sorted sand offers a stable environment, and since marine environments generally are more climatologically stable than terrestrial, it enables the psammobiontic species to be widely distributed and makes factors as climate less important. This is also suggested by the distribution of *E. astridae* new species. The study of the marine psammobiontic rotifers has often been neglected compared to the more species-diverse freshwater habitats, but if more attention were paid to this special habitat, our knowledge would certainly be increased greatly.

The fauna on isolated oceanic islands can theoretically be expected to have low species diversity and a relatively high proportion of endemism (Segers & Dumont 1993a). A total of 14 identifiable species, as recorded in this study, must be considered a low number of species compared to the number of investigated localities. However, it is most likely that this is caused by the lack of stable freshwater bodies rather than isolation by distance. This does not overrule that isolation also plays a role. Of the total number of species, 65% are cosmopolites while three, *L. grandis, L. hastata,* and *L. punctata,* have a tropical/subtropical distribution. Two species, *E. astridae* new species and *E. tectipes,* have at least a boreal and tropical West Atlantic distribution. No endemics were recorded. The dominance of cosmopolites can probably be explained by the fact that migrations of such species are more likely to occur than migration of species with a more limited distribution.

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